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Soundscape analysis and acoustic monitoring document impacts of natural gas exploration on biodiversity in a tropical forest

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ABSTRACT

Natural resource extraction is increasing rapidly in tropical forests, but we lag behind in understanding the impacts of these disturbances on biodiversity. In high diversity tropical habitats, acoustic monitoring is an efficient tool for sampling a large proportion of the fauna across varied spatial and temporal scales. We used passive acoustic monitoring in a pre-montane forest in Peru to investigate how soundscape composition and richness of acoustic frequencies varied with distance from a natural gas exploratory well and with operational phase (construction and drilling). We also evaluated how anuran and avian species richness and vocal activity varied with distance and between phases. Soundscape analyses showed that acoustic frequency similarity was greatest among sites closer to (≤250 m) and farther from (≥500 m) the platform. Soundscapes revealed more frequencies were used during construction and showed a weak trend of increasing frequency richness with increasing distance from the disturbance. Avian species richness and detections increased with distance from the platform, but anuran richness and detections declined with distance. Operational phase did not play a significant role in overall richness or activity patterns of either group. Among birds, insectivore detections increased with distance from the platform, and nectarivores were detected more frequently during the drilling phase. Results demonstrate that acoustic monitoring and soundscape analyses are useful tools for evaluating the impact of development activity on the vocalizing community, and should be implemented as a best practice in monitoring biodiversity and for guiding specific mitigation strategies.

1. Introduction

Oil and gas fulfilled over 55% of the world's energy demand in 2012 (IEA, 2014), and energy consumption globally is predicted to increase by 56% between 2010 and 2040 (EIA, 2013), presumably with direct repercussions for biodiversity. Given the sheer diversity of landscapes affected by hydrocarbon exploration and extraction, quantifying impacts of these operations on biodiversity has proven difficult (Butt et al., 2013; Deichmann and Alonso 2013). While major spills produce clear visible impacts, and studies are often conducted in the aftermath to quantify the effects (e.g. Junoy et al., 2005; Piatt et al., 1990; White et al., 2012), impacts on biodiversity resulting from the overall process of oil and gas exploration and extraction have been little studied, particularly in tropical habitats.

The Western Amazon is under particularly heavy pressure from exploration and extraction of hydrocarbons (Finer et al., 2015), and potential direct and indirect threats to biodiversity from these operations have been previously reviewed (Finer et al., 2008). Expected impacts in tropical forests include avoidance or changes in activity patterns in animal species disturbed by human activity (Klein, 1993; Knopff et al., 2014), and edge effects that modify the spatial distribution of some species after trees are cleared to make room for infrastructure (Broadbent et al., 2008). Sounds produced by construction machinery, camp maintenance and drilling may also mask acoustic signals of vocalizing species, potentially moti-

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vating individuals to alter acoustic activity (Sun and Narins, 2005) or relocate (Francis et al., 2010; Slabbekoorn and Ripmeester, 2008). Anthropogenic disturbance can directly and indirectly affect a variety of behaviors essential to fitness and survival of species including defense, courtship, mating and reproduction (Barber et al., 2010; Kight and Swaddle, 2011; Slabbekoorn et al., 2010; Weilgart, 2007).

While national governments often require some form of environmental assessment and impact evaluation prior to hydrocarbon development, these studies often do not use rigorous protocols and the data are rarely published. The scientific research that has been published shows varying levels of impacts that differ across taxonomic groups. For example, in northern Peru, a study of ocelot and large primate behavior during natural gas seismic exploration activities revealed no change in ocelot activity patterns (Kolowski and Alonso, 2010) nor in the number of primate groups during the disturbance, although the number of individuals per group was reduced (Kolowski and Alonso, 2012). In central Peru, primate encounter rate did not change significantly in the area surrounding a natural gas pipeline before, during and after its construction (Gregory et al. in press). In Ecuador, fewer species of understory insectivorous birds relative to other bird groups were found in plots closer to petroleum operation roads (Canaday and Rivadeneyra, 2001), and elsewhere in Ecuador, there was lower anuran occupancy and abundance in canopy bromeliad tanks closer to roads in an oil concession (McCracken and Forstner, 2014).

These studies are pioneers in the issue of oil and gas impacts on biodiversity in tropical forests, but overall represent a very small effort, particularly given the large scope of hydrocarbon activities in the Western Amazon. Why are there so few studies? Many operations take place in extremely remote areas where access is all but impossible without significant logistical support. When an area is accessible, it can take a long time and require significant funding for researchers to collect the robust data needed to respond to questions about impacts.

While traditional ecological monitoring has focused on direct observations of focal organisms or visual signs of their presence (e.g. Heyer et al., 1994; Wilson et al., 1996), passive acoustic monitoring (PAM) uses recorders placed in a study area to record vocalizations and detect the presence of species (Blumstein et al., 2011). Acoustic methods offer a cost effective way to autonomously collect large amounts of data, providing continuous, simultaneous and permanent records of vocal animals that can be revisited and reanalyzed to answer new questions or to apply new methods (Aide et al., 2013).

Passive acoustic monitoring has been used to evaluate impacts of oil and gas activities on specific focal species or taxonomic groups. In marine environments, it has been used along with visual methods to evaluate impacts of seismic exploration on whales and dolphins (Goold, 1996; Potter et al., 2007) and has recently been identified as a best practice for monitoring marine mammals during seismic activities (Nowacek et al., 2013). In the terrestrial realm, PAM has been employed to evaluate impacts of hydrocarbon operations on specific bird species in North America (Bayne et al., 2008; Francis et al., 2010) as well as elephants in Gabon (Wrege et al., 2010). While acoustic monitoring for focal species can be an indispensable tool to evaluate impacts, the results are limited to the group of interest. In tropical environments where species diversity is generally high, results regarding a single or even a few species are not likely to provide information that can be extrapolated to the community as a whole. This problem can be partially addressed by analyzing the soundscape (Pijanowski et al., 2011), which allows us to visualize all the frequencies that are dominant during certain times of the day or season, providing a framework to describe, compare and analyze acoustic information from many sites and many animal taxa simultaneously.

Soundscapes offer the potential to study biodiversity and community dynamics of vocal species in an ecosystem impacted by immediate threats such as logging, agricultural expansion, and energy development, as well as challenges with more latent impacts such as climate change. Here we aggregate acoustic recordings representing all sources of sound in an area of natural gas exploratory drilling platform in a Peruvian pre-montane forest to develop soundscapes for sites at different distances from anthropogenic activities. We use the soundscapes to investigate how frequency composition and richness vary with distance from the disturbance. We also evaluate how species richness and vocal activity of birds and anurans vary with distance from the platform and between two phases of operations. Finally, we examine whether response to natural gas exploration varies by avian feeding guild, with the expectation that insectivorous birds will respond more acutely to activities, based on previous studies showing understory avian insectivores to be particularly sensitive to anthropogenic disturbance (Canaday, 1996; Strattford and Stouffer, 1999).

2. Materials and methods

2.1. Study area

Our study site is located between the Colorado and Dahuene rivers in the Amarakeri Communal Reserve in the Department of Madre de Dios, Peru in a transition zone between the Andes Mountains and the lowland forests of Amazonia. The area, ranging in elevation from 820 to 1010 masl, is characterized by hilly premontane tropical moist forest and Peruvian Yungas. Locally there is exceptionally high plant species richness (I. Huamantupa, in prep). The area receives on average 6000 mm of rain annually (Condom et al., 2011). January is generally the wettest month (~1100 mm), and there is less precipitation from May through September, although no month of the year receives less than 300 mm of rain (http://www.met.igp.gob.pe/clima/HTML/quincemil.html).

The study was conducted in primary forest surrounding a new exploratory gas well platform. The study site can only reasonably be accessed by helicopter, which prevented data collection prior to disturbance. Clearing the area for the platform began in May 2014, construction was underway by July, and drilling of the exploratory well was initiated in December 2014. We conducted acoustic monitoring for all sound sources within the frequency range 50 Hz–20 kHz for 14 days in September–October (9/26-10/9) 2014 and for 17 days in January–February (1/29-2/13) 2015. The first sampling period coincided with the construction phase (CP) of platform operations while the second sampling period coincided with the drilling phase (DP). While it would have been ideal to obtain a true baseline for soundscape data before any activity began, we were not able to do so due to logistical constraints.

2.2. Data collection

To gather acoustic data we used 10 portable autonomous recorders (LG L70 cellular phones) protected inside a water-proof case (Grace Digital Eco Pod). The recorders were connected by a cable to the case and a microphone (Monoprice – Model 600200) was connected to the case externally.

During each sampling period we placed two recorders, approximately 200 m from one another, at five distances to the west of the platform (100, 250, 500, 750 and 1000 m; Fig. 1). Each recorder was attached with bungee cords to a tree trunk at 1.5 m above the ground, facing south and with the microphone pointing downward. We took photographs of the canopy above each recorder and used the HabitApp application (Version 1.1) to measure canopy cover. We also noted approximate slope, distance to nearest creek and